

## **Sediment Contaminant Patterns Within Coastal Areas of the Southern California Bight: Multivariate Analyses of Bight'98 Regional Monitoring Data**

Charles R. Phillips

*Science Applications International Corporation, 10260 Campus Point Drive,  
San Diego, CA 92121*

*Abstract.*—Patterns in sediment metal, polycyclic aromatic hydrocarbon (PAH), chlorinated pesticide, and polychlorinated biphenyl (PCB) concentrations at 290 sites within coastal, port, harbor, and marina areas of the Southern California Bight (SCB) were evaluated using cluster analysis and principal components analysis (PCA). Cluster analysis identified five primary site groups, with two large groups representing 96% of the total area of the SCB. One of these two groups contained many of the open coastal sites, characterized by relatively coarse-grained sediments (~30% fines), low organic carbon, and low contaminant concentrations. The second large cluster group included a higher proportion of the embayment, marina, and harbor sites, with finer-grained sediments (~70% fines) and proportionately higher mean concentrations of most metals and trace organics. Both site groups were considered representative of SCB background conditions with minimal alterations from contaminant inputs. The other three site groups exhibited elevated concentrations of one or more contaminants, but accounted for only 4% of the total area of the SCB. In particular, two small cluster groups consisted mainly of port, harbor, and marina sites with elevated mean concentrations of certain metals (e.g., Cu, Pb, Sb, and Zn), as well as elevated chlordane, PAH, and PCB concentrations for one of the two site clusters. The fifth cluster group consisted of Palos Verdes Shelf sites that were characterized by high sediment DDT, PCB, Cd, and Ba concentrations, and clearly different from other open coastal sites in the SCB. PCA identified four principal components that explained 67% of the variance in the data set. The first two components (PC1 and PC2) accounted for 52% of the total variance. PC1 was highly loaded with a suite of metals (Cu, Pb, Hg, Zn, Al, and Fe), with high scores primarily for industrialized port and harbor sites. PC2 had high loadings for DDTs, PCBs, Cd, and Cr with highest scores for sites on the Palos Verdes Shelf. PC3 and PC4 each accounted for less than 10% of the total variance, with high loadings for low- and high-molecular weight PAHs and for a subset of metals (Ba, Ni, and Se) and fines, respectively. Although contaminant sources were not analyzed for this study, PC1 and, to a lesser extent, PC3 likely reflected recent industrial inputs to ports, commercial shipping and boatyard operations, and small marina activities. In contrast, PC2, reflected historical, wastewater-derived inputs to the Palos Verdes Shelf. Distinct sediment contaminant patterns were not evident for other large and small wastewater or riverine discharges.

---

### Introduction

Nearshore portions of the Southern California Bight (SCB) are affected to varying degrees by chemical contaminants from multiple sources (Schiff et al., 2000; Eganhouse

and Venkatesan, 1993). Contaminant sources include wastewater and industrial discharges, runoff from urbanized and agricultural areas, commercial and recreational vessel activities, oil and gas operations, and dredged material disposal, as well as atmospheric deposition and natural oil seeps (Anderson et al., 1993). Bottom sediments in coastal environments represent a potential sink for chemical contaminants, including many trace metals, organochlorines (e.g., DDTs and PCBs), and polycyclic aromatic hydrocarbons (PAHs) which typically have strong affinities for particles. Consequently, contaminant patterns in bottom sediments are expected to manifest the chemical characteristics as well as the magnitude and proximity to recent and historical inputs.

The Bight '98 Regional Monitoring Program collected sediment samples at 290 sites throughout coastal portions of the SCB including commercial ports, harbors, and marina areas (Bight '98 Steering Committee, 1998). Concentrations of suites of metals, organochlorines, and PAHs were analyzed using comparable, performance-based methods. Previous studies of sediment contaminants focused primarily on specific sites or portions of the SCB, such as Palos Verdes Shelf (Lee, 1994; Eganhouse et al., 2000), Port of Los Angeles (Malins et al., 1987), and San Diego Bay (McCain et al., 1992; Fairey et al., 1998), which represent only a small fraction of the total nearshore area of the SCB. The 1994 Southern California Bight Pilot Project (SCBPP; Schiff, 1999; Schiff and Gossett, 1998) provided synoptic sampling of coastal portions of the SCB, excluding ports and harbors, for a subset of possible contaminants. The state Bay Protection and Toxics Cleanup Program (BPTCP) evaluated sediment quality within several coastal harbors and embayments (e.g., Fairey et al., 1998; Phillips et al., 1998). State and national Mussel Watch programs evaluated water quality at fixed but widely-spaced, nearshore locations along the coastline and inside ports and harbors (O'Connor, 1996; Stephenson et al., 1995). Mearns et al. (1991) also characterized sediment quality within ports, harbors, and coastal portions of the SCB based on contaminant data from multiple studies conducted over a period of decades. Generally, however, these regional characterizations of sediment contaminant patterns have been limited by the lack of synopticity, methodological incompatibility, and spatially limited sampling. Therefore, the Bight '98 program provided a unique data set for evaluating input sources, pathways, and sinks of anthropogenic contaminants throughout the SCB.

This paper evaluates spatial and compositional patterns in the Bight'98 sediment contaminant data using the multivariate techniques cluster analysis and principal components analysis (PCA). Specifically, the objective was to identify sites with similar contaminant signatures and areal patterns that may infer sources and transport pathways. PCA and cluster analyses are particularly effective as exploratory tools for evaluating compositional patterns within large and complex data sets, and can reveal relationships among parameters and sampling locations that provide insight into contaminant sources and sinks. PCA was used previously by Phillips et al. (1997) to evaluate possible sources of sediment contaminants for the San Pedro Shelf area of the SCB, and cluster analysis was used by Anderson and Gossett (1987) to evaluate patterns in sediment PAH concentrations at 24 sites in the SCB. Although sediment contaminant patterns at selected sites within the SCB have been well-characterized by previous studies, multivariate analyses are considered useful for interpreting larger-scale spatial patterns which might be related to similar input sources or transport pathways. These results are also expected to provide a regional framework for interpreting sediment toxicity and biological community data.

Methods and Materials

Sediment samples were collected during July through September, 1998, at 290 sites throughout the SCB (Figure 1). The station array used for the Bight'98 Program was based on a variable-density, stratified random sampling design described by Stevens (1997). Sites were assigned *a priori* to one of nine strata – large publicly-owned treatment works (LPOTW), small POTW (SPOTW), mid-shelf POTW, river, shallow shelf, mid-shelf, marina, port, and bay/harbor. Samples were from the 0–2 cm surface layers of grabs (Van Veen grab) as representative of recently deposited sediments.

Analytical methods and data quality objectives for chemical analyses of sediment samples were described by the Bight '98 Steering Committee (1998). Target analytes and corresponding ranges in method detection limits (MDL) are listed in Table 1. Variations in MDLs for individual analytes reflected differences among participating laboratories in specific methods and capabilities. Although chemical analyses were performed by multiple laboratories, extensive intercalibrations were performed prior to and during the study to ensure data comparability (Gossett et al., 2003).

A complete data matrix was prepared for individual and summed variables listed in Table 2 and all 290 sites. Values corresponding to one-half the reporting limits were substituted for non-detectable results. Values for summed variables (e.g., total DDTs) represented the summed concentrations of all detected components, while concentrations of non-detected components were treated as zero. In cases where all components of summed variables were below detection limits, values corresponding to one-half the method detection limits for individual components were substituted, and surrogate values were summed. Prior to PCA, concentrations of individual variables were standardized by setting the mean to zero and variance to one. PCA then was performed on the correlation matrix, and factors were rotated using Varimax rotation to better align the directions of factors with the original variables, thereby making the factors more interpretable. Factor scores from the first four principal components were saved and analyzed by hierarchical cluster analysis

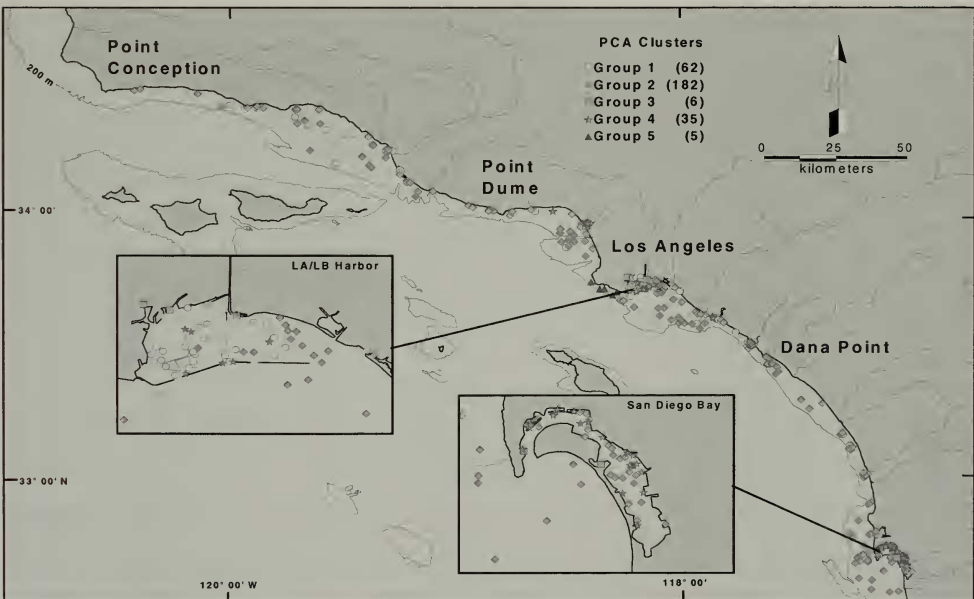


Fig. 1. Spatial Distributions of Site Clusters.

Table 1. Analytes and Method Detection Limit (MDL) Ranges for Bight '98 Sediment Samples.

Pest/PCBs	MDL (ng g <sup>-1</sup> )	PAHs	MDL (ng g <sup>-1</sup> )	Metals	MDL (µg g <sup>-1</sup> )
α-Chlordane	0.01-1	Naphthalene	5-36	Ag	0.06-0.2
γ-Chlordane	0.01-1	1-Methylnaphthalene	5-39	Al	500
o,p'-DDD	0.02-1	2-Methylnaphthalene	5-39	As	0.08-0.62
o,p'-DDE	0.04-1	2,6-Dimethylnaphthalene	5-43	Ba	0.04-50
o,p'-DDT	0.02-1	1,6,7-Trimethylnaphthalene	5-39	Be	0.06-0.2
p,p'-DDD	0.03-1	Biphenyl	5-42	Cd	0.008-0.5
p,p'-DDE	0.02-1	Acenaphthene	5-42	Cr	1-16
p,p'-DDT	0.02-1	Acenaphthylene	5-25	Cu	1.9-7
PCB18	0.14-1	Fluorene	5-46	Fe	500
PCB28	0.24-1	Phenanthrene	5-37	Hg	0.005-0.2
PCB37	0.23-1.7	1-methylphenanthrene	5-29	Ni	1.2-4.2
PCB44	0.22-1	Anthracene	5-35	Pb	1-9.3
PCB49	0.17-1.3	Benzo(a)anthracene	5-26	Sb	0.05-10
PCB52	0.27-1.6	Benzo(a)pyrene	5-49	Se	0.11-1
PCB66	0.25-1	Benzo(e)pyrene	5-48	Zn	1.4-30
PCB70	0.22-1	Fluoranthene	5-39		
PCB74	0.23-7.9	Pyrene	5-27		
PCB77	0.13-3.7	Chrysene	5-36		
PCB81	0.19-4.7	Benzo(ghi)perylene	5-63		
PCB87	0.1-1.8	Benzo(b)fluoranthene	5-44		
PCB99	0.18-4.1	Benzo(k)fluoranthene	5-49		
PCB101	0.2-1.2	Indeno(cd)pyrene	5-33		
PCB105	0.18-1	Dibenzo(ah)anthracene	5-33		
PCB110	0.1-1	Perylene	5-34		
PCB114	0.1-1				
PCB118	0.21-1.1				
PCB119	0.17-1.2				
PCB123	0.13-9.6				
PCB126	0.11-1.1				
PCB128	0.06-8.9				
PCB138	0.13-1.9				
PCB149	0.17-1.7				
PCB151	0.14-1.1				
PCB153	0.44-1.2				
PCB156	0.1-1.8				
PCB157	0.15-5.6				
PCB158	0.09-1.1				
PCB167	0.12-5.0				
PCB168	0.44-1.4				
PCB169	0.19-1.7				
PCB170	0.17-1.6				
PCB177	0.22-2.3				
PCB180	0.19-2.7				
PCB183	0.15-1.4				
PCB187	0.2-1.3				
PCB189	0.18-1.6				
PCB194	0.15-1.8				
PCB201	0.2-2.3				
PCB206	0.29-5.8				

Table 2. Variables for PCA.

Metals	Ag, Al, As, Ba, Be, Cd, Cr, Cu, Fe, Hg, Ni, Pb, Sb, Se, Se, Zn
Total DDT	Summed concentrations of detected o,p'- and p,p'- isomers of DDT, DDE, and DDD
Total PCB	Summed concentrations of detected congeners: 18, 28, 37, 44, 49, 52, 66, 70, 74, 77, 81, 87, 99, 101, 105, 110, 114, 118, 119, 123, 126, 128, 138, 149, 151, 153, 156, 157, 158, 167, 168, 169, 170, 177, 180, 183, 187, 189, 194, 201, 206
Total Chlord	Summed concentrations of detected $\alpha$ - and $\gamma$ -chlordane
Low Molecular Weight PAH (LPAH)	Summed concentrations of detected two and three-ring PAHs: naphthalene, 1-methyl-, 2-methyl-, 2,6-dimethyl-, 1,6,7-trimethyl-naphthalenes, biphenyl, acenaphthene, acenaphthylene, fluorene, phenanthrene, 1-methylphenanthrene, anthracene
High Molecular Weight PAH (HPAH)	Summed concentrations of detected four and five-ring PAHs: fluoranthene, pyrene, chrysene, benzo(a)pyrene, benzo(e)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(cd)pyrene, dibenzo(ah)anthracene, perylene, benzo(ghi)perylene
TOC	Total organic carbon
Fines	Silts + clays: particle diameter <63 microns

using the Ward clustering option. The number of primary cluster groups was selected by visually inspecting the plot of cluster distance between successive cluster joins in the dendrogram and distributions of data points for bivariate plots of principal component scores. PCA and cluster analyses were performed using JMP software (SAS Inst., 2001).

Area-weighted mean (AWM) concentrations for individual station clusters were calculated as follows:

$$m = \frac{\sum_{i=1}^n (p_i * w_i)}{\sum_{i=1}^n w_i}$$

where  $m$  = Area weighted mean concentration for population  $j$ ,  $p_i$  = Parameter value (e.g., concentration) at station  $i$ ,  $w_i$  = area weight for station  $i$ , equal to the inverse of the inclusion probability,  $n$  = Number of stations in population  $j$ . The standard error was calculated as follows:

$$\text{Standard Error} = \sqrt{\frac{\sum_{i=1}^n ((p_i - m) * w_i)^2}{\left(\sum_{i=1}^n w_i\right)^2}}$$

Confidence intervals were 1.96 times the standard error.

## Results

### Cluster Analysis

The dendrogram obtained from cluster analysis of PCA scores indicated five primary cluster groups (Figure 2) with varying numbers of sites per cluster (Table 3). Spatial distributions of the cluster groups are shown in Figure 1. The two largest cluster groups

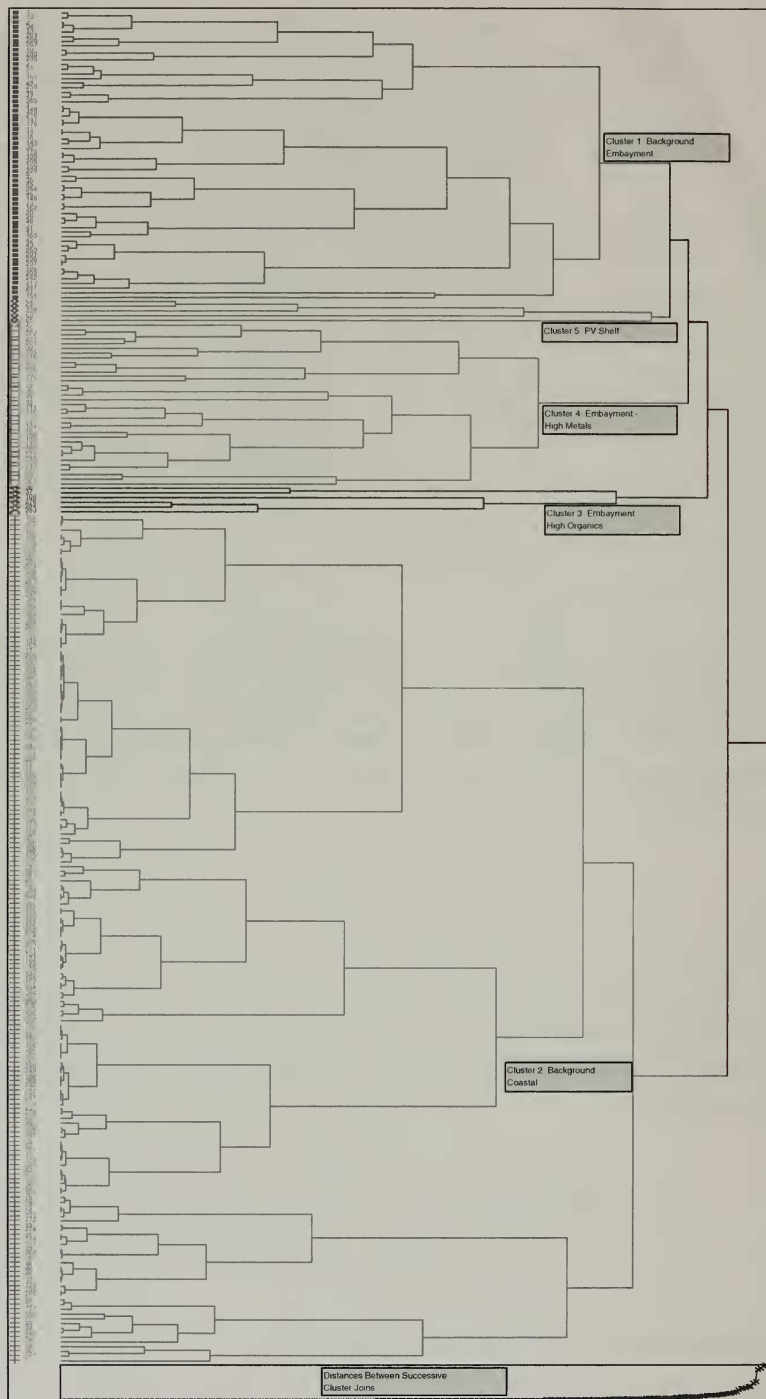


Fig. 2. Dendrogram from cluster analysis of PCA scores. Cluster distances between successive cluster joins are shown beneath the dendrogram.

Table 3. Summary of Cluster Analysis Results and Characterizations of Principal Site Cluster Groups.

Cluster	No. Sites	Area		Proportion of Sites by Strata <sup>a</sup>				Description
		km <sup>2</sup>	%	POTW	River	Ports/ Harbor	Other Coastal	
1	62	704	22	14	8	58	19	Background Embayment
2	182	2,430	74	29	14	21	36	Background Coastal
3	6	8.7	0.3	0	17	84	0	Embayment – High Organics
4	35	89	3	0	0	97	3	Embayment – High Metals
5	5	47	1	80	0	0	20	Palos Verdes Shelf

<sup>a</sup> POTW = LPOTW, SPOTW, and mid-shelf POTW strata; River = river and river-gradient strata; Ports/Harbor = ports, harbors, marina, and other port strata; Other Coastal = shallow shelf, mid-shelf, and historical reference

(groups 1 and 2) accounted for 84% of the 290 sites and 96% of the corresponding study area, whereas the remaining three clusters combined accounted for only 46 of the sites and approximately 4% of the area.

Cluster group 2, which contained the largest number of sites and accounted for the greatest proportion of the study area, comprised 148 shelf and 38 embayment sites, consisting of shallow and mid-shelf (36%), LPOTW and SPOTW (13% and 16%, respectively), river (14%), and port/harbor/marina (21%) strata. All of the shallow- and mid-shelf sites on the 30-m and 60-m depth contours, coinciding with locations sampled historically for the SCCWRP Reference Site Surveys (SCCWRP, 1987, 1992), were part of this site cluster. Sediments were characterized by low proportions of fines, low TOC concentrations, and consistently lower contaminant concentrations than those of other cluster groups (Table 4).

Cluster group 1 comprised a relatively higher proportion of port, marina, and bay/harbor sites (21%, 24%, and 13%, respectively) and lower proportion of coastal (primarily mid-shelf, SPOTW, and river) sites, than group 2. Many of the coastal sites included in cluster group 1 were from a depositional region in the eastern Santa Barbara Channel characterized by relatively high proportions (46 to 99%) of fine-grained sediments, described previously by Kolpack (1986). Cluster group 1 sediments contained higher average TOC content, and, with the exceptions of Ag and Sb, higher contaminant concentrations than those in cluster group 2. These differences likely are due in large part to the relatively higher proportions of fines comprising cluster group 1 sediments and strong affinities of contaminants for fine-grained sediments.

With one exception (site 2382 in Santa Monica Bay), cluster groups 3 and 4 consisted exclusively of industrialized harbor and marina strata sites. Cluster group 3 contained three sites from Ports of Los Angeles/Long Beach, two sites from San Diego Bay, and one site in Marina del Rey. All of these sites were located in the inner portions of ports and harbors near industrial operations with limited circulation. Cluster group 4 comprised 21 port, harbor, and marina sites in San Diego Bay, seven marina sites in Newport and Marina del Rey harbors, six sites in Port of Los Angeles/Long Beach, and one shallow shelf site (2382) that, unlike the cluster group 3 sites, was not confined to the inner portion of industrialized harbor areas. Cluster groups 3 and 4 sediments typically contained elevated Cu, Hg, Pb, Zn, and Sb concentrations, whereas cluster group 3 sites also were distinguished by elevated LPAH, HPAH, PCB, and chlordanes concentrations. Cluster group 5 comprised five sites on the Palos Verdes Shelf (four LPOTW and one shallow-shelf strata), generally northwest of the JWPCP outfalls, characterized by elevated DDT, PCB, Cd, and Ba concentrations.

Table 4. Area Weighted Mean Concentration by Cluster Group of Sediment Fines (%), TOC (%), Metals ( $\mu\text{g g}^{-1}$ ), and Organics ( $\text{ng g}^{-1}$ ). Numbers in parentheses are the lower and upper confidence limits.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
n	62	182	6	35	5
Fines	74 (65, 84)	30 (25, 35)	64 (48, 79)	62 (49, 75)	26 (0, 54)
TOC	1.5 (1.2, 1.7)	0.51 (0.43, 0.58)	2.2 (1.4, 2.9)	1.2 (0.87, 1.6)	2.2 (1.6, 2.8)
Ag	0.18 (0.13, 0.22)	0.38 (0.14, 0.61)	0.82 (0.01, 1.6)	1.6 (1.0, 2.1)	0.86 (0, 2.1)
Al	15,700 (13,600, 17,900)	9,000 (7,780, 10,200)	23,600 (14,300, 33,000)	26,100 (16,300, 36,000)	11,000 (5,420, 16,600)
As	8.7 (7.3, 10)	4.3 (3.8, 4.8)	11 (5.5, 17)	9.5 (8.2, 11)	8.9 (7.4, 10)
Ba	258 (170, 346)	82 (67, 96)	111 (48, 173)	111 (101, 122)	831 (527, 1,130)
Be	0.56 (0.48, 0.64)	0.43 (0.29, 0.57)	0.65 (0.22, 1.1)	0.74 (0.50, 0.98)	0.58 (0.47, 0.68)
Cd	0.57 (0.45, 0.69)	0.25 (0.18, 0.32)	0.66 (0.03, 1.3)	0.41 (0.27, 0.56)	2.9 (1.3, 4.4)
Cr	39 (36, 42)	22 (19, 26)	49 (23, 76)	51 (46, 55)	71 (17, 125)
Cu	24 (20, 29)	8.7 (7.4, 9.9)	85 (58, 112)	100 (43, 157)	33 (0, 71)
Fe	30,200 (25,100, 35,300)	14,800 (13,300, 16,400)	28,400 (16,600, 40,200)	30,600 (24,800, 36,600)	21,000 (13,200, 28,700)
Pb	15 (12, 17)	11 (6.7, 14)	51 (26, 76)	60 (52, 68)	23 (5.7, 40)
Hg	0.10 (0.09, 0.12)	0.08 (0.06, 0.10)	0.24 (0.16, 0.32)	0.50 (0.26, 0.74)	0.20 (0, 0.40)
Ni	49 (31, 68)	12 (9.9, 13)	22 (9.2, 35)	22 (19, 25)	18 (11, 26)
Sb	0.42 (0.26, 0.58)	1.5 (1.0, 2.0)	4.4 (1.9, 7.0)	16 (2.3, 31)	0.83 (0.66, 1.0)
Se	1.5 (1.2, 1.8)	0.54 (0.40, 0.68)	0.46 (0.34, 0.58)	0.53 (0.40, 0.66)	0.60 (0.11, 1.1)
Zn	95 (82, 107)	40 (35, 45)	205 (114, 297)	161 (98, 224)	88 (31, 145)
Total Chlord	0.72 (0.45, 0.99)	0.42 (0.37, 0.47)	8.8 (0.71, 17)	1.3 (0.41, 2.2)	0.5 (0.5, 0.5)
Total DDT	42 (5.8, 79)	18 (7.0, 30)	91 (0, 187)	18 (11, 26)	1,600 (0, 3,290)
Total PCB	6.5 (2.5, 11)	4.6 (1.9, 7.3)	126 (3.2, 250)	21 (5.5, 37)	115 (3.2, 226)
LPAH	29 (7.7, 51)	15 (11, 18)	1,070 (596, 1,540)	55 (14, 96)	62 (0, 152)
HPAH	195 (111, 280)	27 (16, 38)	6,950 (4,070, 9,830)	569 (140, 997)	253 (0, 510)



### *PCA Results*

The first four principal components of the PCA accounted for 67% of the total variance of the data set (Table 5). Principal components 1 and 2 (PC1 and PC2) explained 41% and 11%, respectively, of the variance, while PC3 and PC4 combined accounted for 16% of the variance. All other factors explained less than 5% of the variance and were not retained for further evaluation.

The highest PC1 loadings were for Cu, Hg, Zn, Pb, Al, and Fe. High factor loadings imply that these metals contributed to and strongly influenced the principal component (Zitko, 1994). The highest scores for PC1 corresponded primarily to harbor and port strata sites, especially in San Diego Bay and Ports of Los Angeles/Long Beach, as well as marina strata sites within Newport and Marina del Rey harbors and LPOTW strata sites near wastewater outfalls on the Palos Verdes Shelf. Factor scores give the positions of the samples in coordinates of the principal components, and the magnitude of scores corresponds to the extent to which individual sites reflect these attributes (i.e., elevated concentrations of metals with high loadings) and the amount of information for that site explained by the factor. High loadings for Fe and Al suggest that PC1 also included portions of the variance associated with natural patterns in sediment geochemistry (Schiff and Weisberg, 1999).

The highest loadings on PC2 were for DDT, PCB, Cd, and Cr. High PC2 scores were, with minor exceptions, associated exclusively with LPOTW strata sites near the JWPCP and Hyperion outfalls on the Palos Verdes Shelf and Santa Monica Bay, respectively. Low and high molecular weight PAHs and, to a lesser extent, chlordane had the highest loadings on PC3. The highest PC3 scores were associated with port strata sites in San Diego Bay and Ports of Los Angeles/Long Beach and LPOTW strata sites associated with JWPCP and Hyperion outfalls. PC4 appeared to be associated mainly with Se, Ni, Ba, and fines, although the magnitude of the highest loading values were all less than 0.8. Sites with the highest PC4 scores corresponded to LPOTW, port, and marina strata, especially within San Diego Bay.

Bivariate plots of PCA scores shown in Figure 3 illustrate differences in sediment contaminant patterns for individual cluster groups. Density ellipses were computed from the bivariate normal distribution fits to the X and Y variables, and the ellipses delineate expected distributions of 95% of the data (PCA scores) for individual cluster groups. Relatively large ellipses associated with cluster groups 3 and 5 reflect the correspondingly large variances in contaminant concentrations. The plot of PC1 versus PC2 shows separation along PC1 for cluster groups 3 and 4, reflecting the elevated concentrations of highly loaded metals (e.g., Cu, Zn, and Pb) within these port and harbor sites, and separation of cluster group 5 along PC2 associated with elevated concentrations of DDT, PCB, and Cd on the Palos Verdes Shelf. Although cluster group 2 overlapped with that of cluster group 1, the positive offset along PC1 reflected the consistently higher mean sediment metal concentrations associated with the cluster group 1 sites. Biplots of PC2 versus PC3 show considerable overlap along PC3 for all but cluster group 3, reflecting the presence of elevated PAH concentrations at these inner harbor sites.

### Discussion

Spatial patterns for sediment contaminants described by PCA and cluster analyses were internally consistent and, with some exceptions, in general agreement with results from previous site-specific and regional SCB studies (e.g., Mearns et al., 1991). PCA and cluster analyses indicated that the major portion (74%) of the SCB, primarily comprising

Table 5. Rotated Factor Pattern for PCA Factors (PC 1-4). Italicized numbers are factor loadings &gt;0.6 or &lt;-0.6.

	PC1	PC2	PC3	PC4
Ag	0.321	0.585	-0.032	0.053
Al	<i>0.793</i>	-0.057	0.159	-0.368
As	0.496	0.147	0.201	-0.063
Ba	-0.003	0.276	-0.032	<i>-0.602</i>
Be	0.464	0.081	0.058	-0.282
Cd	0.069	<i>0.823</i>	0.126	-0.355
Cr	0.551	<i>0.639</i>	0.165	-0.414
Cu	<i>0.838</i>	0.095	0.227	-0.078
Fe	<i>0.706</i>	0.075	0.177	-0.588
Hg	<i>0.750</i>	0.208	0.096	0.045
Ni	0.206	0.075	0.125	<i>-0.643</i>
Pb	<i>0.734</i>	0.244	0.299	-0.176
Sb	0.487	0.062	-0.118	0.301
Se	-0.012	0.086	0.096	<i>-0.722</i>
Zn	<i>0.799</i>	0.136	0.405	-0.285
Total Chlord.	0.093	0.016	0.594	-0.187
Total DDT	-0.034	<i>0.874</i>	0.035	-0.111
Total PCB	0.197	<i>0.708</i>	0.558	-0.123
LPAH	0.146	0.163	<i>0.896</i>	-0.046
HPAH	0.239	0.035	<i>0.861</i>	0.015
TOC	0.451	0.281	0.382	-0.534
Fines	0.577	-0.054	0.187	<i>-0.607</i>
% Total Variance	40.7	10.6	8.7	7.3

areas of the open coast and shelf represented by cluster group 2, was characterized by sediments with generally low contaminant concentrations. The exception, represented by cluster group 5, reflected the uniqueness of the Palos Verdes Shelf compared to other shelf sites. A second group of sites represented by cluster group 1, comprising 22% of the SCB area, included harbor sites characterized by finer grained sediments with a higher organic content than those for cluster group 2. Although the average contaminant concentrations were higher than those of cluster group 2 sites, the differences were consistent with the higher proportions of fine grained sediments and not necessarily due to greater contaminant inputs. Cluster groups 3 and 4 represented subsets of port, harbor, and marina sites containing elevated sediment contaminant concentrations but, together with cluster group 5, represented less than 5% of the SCB area.

Although results from the multivariate analyses were consistent with previous studies, they did not indicate a close correspondence between cluster groups and the original site strata. Instead, primary distinctions appeared to be between relatively uncontaminated (cluster groups 1 and 2) and contaminated (cluster groups 3, 4, and 5) sites, while distinctions between cluster groups 1 and 2 appeared to be driven by differences in grain size and proportional differences in bulk contaminant concentrations. The background clusters included sites from all strata. Other than the JWPCP outfalls on the Palos Verdes Shelf, LPOTW strata sites near the Hyperion, OCSD, and Point Loma outfalls, and most SPOTW sites, were associated with cluster group 2 and, to a lesser extent, with cluster group 1. Associations of LPOTW sites near the OCSD and Point Loma outfalls with the background coastal site cluster are reasonable based on the general absence of significant sediment contamination in the vicinity of these outfalls (Phillips et al., 1997; Zeng and

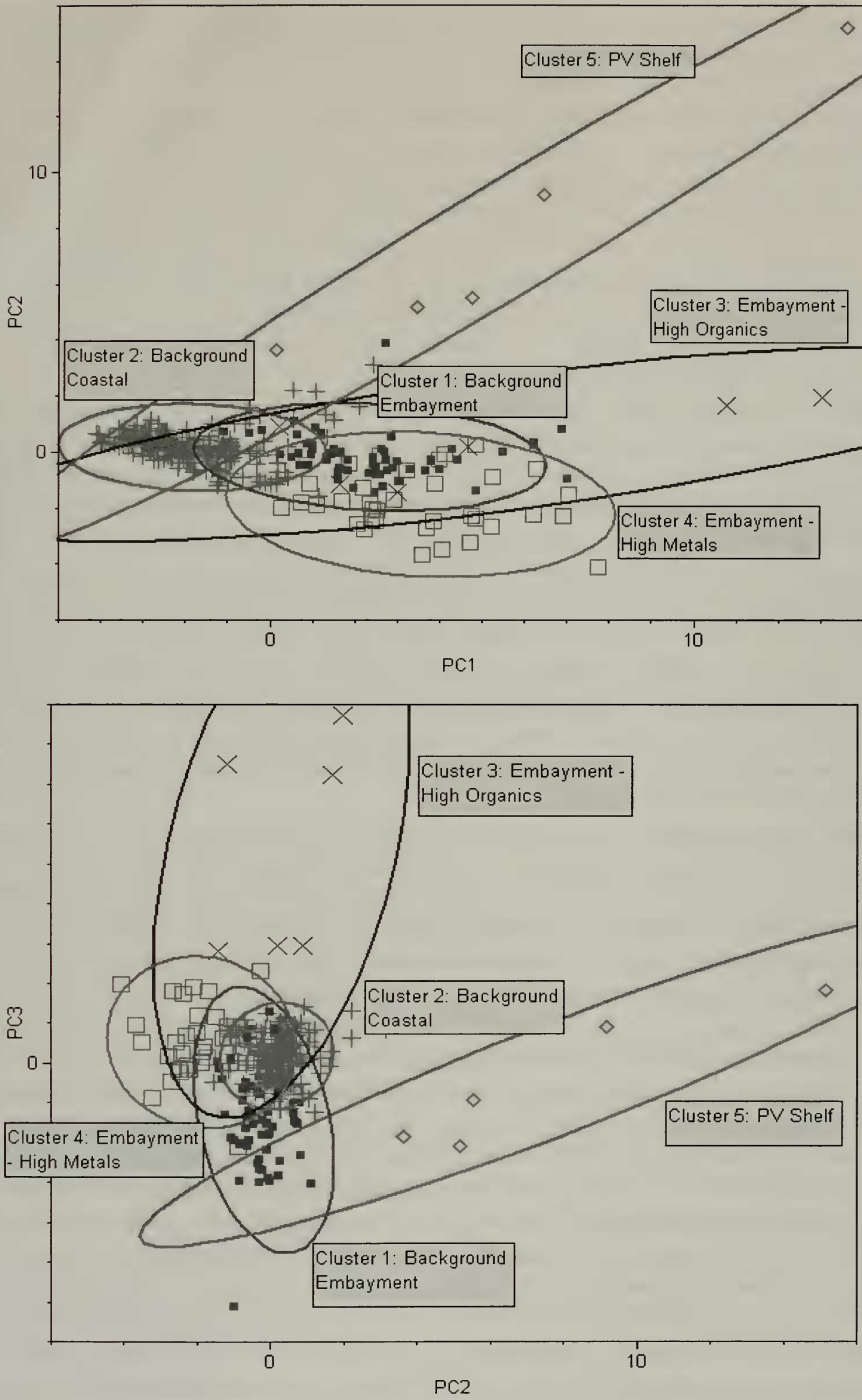


Fig. 3. Bivariate plots of principal component scores: (A) PC1 vs PC2 and (B) PC2 vs PC3. 95% Density ellipses are shown for individual site clusters.

Vista, 1997). In contrast, sediments in the vicinity of the Hyperion outfall in Santa Monica Bay contained elevated Ag ( $1.4\text{--}7.5 \mu\text{g g}^{-1}$ ), Hg ( $0.13\text{--}0.7 \mu\text{g g}^{-1}$ ), and DDT (up to  $100 \text{ ng g}^{-1}$ ) concentrations, and sites near the outfall terminus had high scores for PC2 and PC3. During the 1994 SCBPP, approximately 80% of the sites in Santa Monica Bay were enriched in three or more metals, especially Ag, Cd, and Cr (Schiff and Weisberg, 1999) that likely represented residual contamination from discontinued sludge discharges (Zeng and Venkatesan, 1999). Regardless, sediment contaminant patterns near the Hyperion outfall appear to be more similar to those of other shelf areas described by cluster group 2 than to contaminant patterns associated with the Palos Verdes Shelf and cluster group 5. However, removal of outlier data associated with the Palos Verdes Shelf sites likely would have resulted in greater distinctions for cluster analysis between Hyperion and other LPOTW sites.

It is also noteworthy that other than a single site near the mouth of the Los Angeles River, in the Port of Long Beach, river strata sites occurred only in the background cluster groups 1 and 2. Sediments from river mouth locations did not exhibit any discernable chemical signatures (i.e., for the suite of measured contaminants) other than slightly elevated chlordane concentrations, that might be associated with runoff. Chlordanes were moderately loaded on PC3, but this factor explained less than 10% of the total variance of the data set, and none of the river strata sites had particularly high scores for PC3. The absence of a strong runoff signal may be due in part to physical mixing processes which typically minimize deposition and accumulation of particle-associated contaminants at the mouths of coastal rivers. Regardless, this is contrary to expectations because previous studies have indicated that river discharges can be significant sources of runoff-derived pollutants as well as fine-grained sediments to coastal areas of the SCB (Schiff et al., 2000).

While cluster groups 1 and 2 were characterized as background sites for embayment and open coastal areas, respectively, it is useful to compare the area-weighted mean (AWM) concentrations calculated for these cluster groups to corresponding reference values reported previously for the SCB (Table 6). Cluster group 2 AWM values for metals and several organic contaminants were generally comparable to average concentrations reported for the 1985 and 1990 Reference Site Surveys (SCCWRP, 1987, 1992), as well as AWM concentrations for reference site locations sampled as part of the Bight'98 program. The AWM metal concentrations for cluster groups 1 and 2 also show reasonably good agreement with values predicted using regression coefficients for baseline metal:iron relationships developed by Schiff and Weisberg (1999) for non-enriched sediments within the SCB. This further supports the characterization of cluster group 2 sediments as representative of "background coastal" conditions. However, the AWM concentrations for Ag, Cd, and Pb in cluster group 2 sediments were up to severalfold higher than predicted baseline levels, indicating some degree of sewage- and/or runoff-derived contamination. Furthermore, sediments from cluster groups 1 and 2 typically contained measurable amounts of synthetic organic compounds (DDT, PCB, and chlordanes) which are not consistent with pollution-free conditions. This is not surprising given that the SCBPP detected DDT in 89% of the SCB sediments during 1994 (Schiff et al., 2000), and Schiff and Weisberg (1999) concluded that 61% of SCB sediments contained elevated concentrations of one or more metals. Therefore, while the AWM concentrations reflect minimal apparent alterations and represent background conditions throughout a large portion of the SCB, cluster groups 1 and 2 sediments were not "pollution-free". In many cases, the distributions of concentration values for

Table 6. Comparisons of Bight '98 Cluster Area Weighted Mean (AWM) and Baseline Concentrations.

	Measured AWM		Predicted <sup>a</sup>		1985 and 1990 Reference Site Surveys <sup>b</sup>				Bight '98 Historical Sites <sup>c</sup>		Pollution-Free Baseline <sup>d</sup>
	Cluster 1	Cluster 2	Cluster 1	Cluster 2	30 m	60 m	30 m	60 m	30 m	60 m	
	Ag	0.18	0.38	0.22	0.10	0.01	0.03	0.1	0.25	0.30	
As	8.7	4.3	7.2	4.3					3.2	4.3	
Cd	0.57	0.25	0.30	0.15	0.13	0.14	0.26	0.24	0.21	0.18	0.4
Cr	39	22	50	24	18	25	17	26	14	20	25
Cu	24	8.7	20	9.0	5.7	10	5.3	9.2	5.6	9.1	9
Fe	30,200	14,800					11,000	18,000	10,600	15,400	
Pb	15	10	14	7.3	2.9	4.8	4.4	6.9	7.0	5.2	10
Ni	49	12	29	14	9.0	13	8.0	11	7.3	11	15
Zn	95	40	93	45	31	48	29	45	29	39	44
Total DDT	42	18			9.1	19	5.4	13	3.9	6.9	
Total PCB	6.5	4.6			11	19	7.1	12	0.5	1.2	
LPAH	29	15							20	20	
HPAH	195	27			39	20	24	26	32	29	

<sup>a</sup> Predicted values based on baseline regression coefficients (slope and intercept) for metal:iron relationships in SCB sediments from sites distant from known point and non-point sources of pollution developed by Schiff and Weisberg (1999).

<sup>b</sup> Average values for 30-m and 60-m sites sampled in 1985 and 1990 for the SCCWRP Reference Site Surveys (SCCWRP, 1987, 1992); total DDT is the sum of five isomers, total PCB is sum of two Aroclors, and HPAH represents sum of 30 LPAH and HPAH.

<sup>c</sup> Averages for historical 30-m and 60-m sites corresponding to SCCWRP Reference Site Survey locations.

<sup>d</sup> from Katz and Kaplan (1981).

individual parameters, as represented by the 95% confidence intervals, for cluster groups 1 and 2 overlapped with those of the other site clusters (Table 4). This illustrates the difficulty distinguishing contaminated sediments based on bulk contaminant concentrations, which has important implications for regulatory-based programs such as waste discharge monitoring and dredged material testing.

In contrast with cluster groups 1 and 2, sites comprising cluster groups 3, 4, and 5 were characterized by elevated concentrations of various metals, PAHs, and organochlorines. Several of these sites, particularly in cluster groups 3 and 5, exhibited consistently high scores on one or more of the PCA factors. Regardless, the magnitude of measured contaminant concentrations was consistent with those reported by previous studies and therefore considered reasonable descriptions of SCB sediment contaminant patterns. In particular, the magnitude and distributions of contaminants such as DDT and PCB in Palos Verdes Shelf sediments have been well-documented. Previous studies (Lee, 1994; Eganhouse and Pontolillo, 2000) concluded that histories of waste emissions to the Palos Verdes Shelf were recorded in the depositional chronologies of sediment cores. Further, surface contaminant concentrations on the Palos Verdes Shelf remain elevated despite large reductions in mass emissions. The presence of contaminants in surface sediments may be due to bioturbation and remobilization of historically buried sediments with elevated contaminant concentrations. Other studies have also indicated that remobilized contaminants are subject to dispersion to other areas of the SCB (Zeng and Venkatesan, 1999). As a result, the Palos Verdes Shelf represents a secondary source for DDT to other

parts of the SCB, and may contribute to the presence of measurable organochlorines in cluster group 2 sediments. Because the Palos Verdes Shelf is a reservoir for large quantities of DDT and PCB, and remobilization of contaminants represents an ongoing threat to biological resources and human health, sediment remediation and contaminant management projects are being evaluated to address these issues (Palermo et al., 1999).

Embayment sites contributing to cluster groups 3 and 4 were characterized by elevated concentrations of selected metals and PAHs that may be from industrial input sources. Elevated metal (Cu, Hg, and Zn) concentrations can be associated with multiple source types that include industrial activities, hull cleaning and dissolution of anti-fouling hull paints in ports, harbors, and marinas, and urban runoff. Elevated PAH concentrations in sediments at cluster 3 sites included both high and low molecular weight compounds associated with both petroleum and combustion sources potentially derived from fuel spills and urban runoff. Sediment contaminants at the cluster group 3 sites likely reflect proximity to input sources as well as hydrological properties that promote deposition and accumulation of particulate-bound contaminants within the inner portions of industrialized harbors, such as commercial slips and dredged channels with limited circulation.

Compositional data for contaminant input sources to the Bight (e.g., POTW discharges, river and urban runoff, atmospheric deposition) are not presently available to support source apportionment estimates. Additionally, it should be noted that while sediments collected for this program were from the surface 2-cm layer of grab samples, deposition rates are expected to vary considerably throughout the Bight. Also, some areas within harbors and marinas may have been dredged prior to sampling. Thus, contaminant levels in sediments measured at individual sites were not necessarily representative of inputs over the same, fixed time period. Regardless, the overall patterns indicated by these results should be useful for interpreting patterns in biological communities, comparisons between bulk contaminant concentrations and effects thresholds, and sediment bioassay results from the Bight '98 and subsequent regional monitoring programs.

### Conclusions

Of the five station groups delineated by cluster analysis, two groups comprising the majority of coastal and embayment sites and representing 94% of the study area, were characterized by relatively low contaminant concentrations. The primary distinction between the two station groups appears to be related to relatively finer sediment texture, and correspondingly higher contaminant concentrations, at embayment sites. The other three station groups were characterized by elevated concentrations of one or more contaminant classes but represented a relatively small portion of the total area of the SCB. Two of the cluster groups consisted almost exclusively of sites from enclosed portions of industrialized ports and marinas with high sediment trace metal and organic concentrations. The final site cluster comprised Palos Verdes Shelf sites, which reflected residual contamination from historical waste discharges. By contrast, other POTW and river sites lacked distinctive chemical signatures and were largely indistinguishable from other open-coastal background sites.

### Acknowledgments

Sediment contaminant data were generated by analytical chemistry laboratories participating in the Bight '98 Program. Jim Noblet provided the data matrix and Shelly

Moore provided graphics support. Helpful suggestions were provided by the Sediment Chemistry Working Group for the Bight '98 Regional Monitoring Program, Ananda Ranasinghe (SCCWRP), and two anonymous reviewers.

### References

- Anderson, J.W. and R.W. Gossett. 1987. Polynuclear Aromatic Hydrocarbon Contamination in Sediments from Coastal Waters of Southern California. Final Report to California State Water Resources Control Board, Sacramento, CA.
- , D.J. Reish, R.B. Spies, M.E. Brady, and E.W. Segelhorst. 1993. Human impacts. Chapter 12 In M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). *Ecology of the Southern California Bight: A Synthesis and Interpretation*. University of California Press, Berkeley, CA.
- Bight '98 Steering Committee. 1998. Southern California Bight 1998 Regional Marine Monitoring Survey: Coastal Ecology Workplan, Pp. 9,58–59 (Appendix B).
- Eganhouse, R.P. and J. Pontolillo. 2000. Depositional history of organic contaminants on the Palos Verdes Shelf, California. *Mar. Chem.*, 70:317–338.
- , ———, and T.J. Leiker. 2000. Diagenetic fate of organic contaminants on the Palos Verdes Shelf, California. *Mar. Chem.*, 70:289–315.
- and M.I. Venkatesan. 1993. Chemical oceanography. Chapt. 3 In M.D. Dailey, D.J. Reish, and J.W. Anderson (eds.). *Ecology of the Southern California Bight: A Synthesis and Interpretation*. University of California Press, Berkeley, CA.
- Fairey, R., C. Roberts, M. Jacobi, S. Lamerdin, R. Clark, J. Downing, E. Long, J. Hunt, B. Anderson, J. Newman, R. Tjeerdema, M. Stephenson, and C. Wilson. 1998. Assessment of sediment toxicity and chemical concentrations in the San Diego Bay region, California USA. *Environ. Toxicol. Chem.*, 17:1570–1581.
- Gossett, R.W., R. Baird, K. Christensen, and S.B. Weisberg. 2003. Making performance-based chemistry work: How we created comparable data among laboratories as part of a Southern California marine regional assessment. *Environ. Monitor. and Assess.*, 81:269–287.
- Katz, A. and I.R. Kaplan. 1981. Heavy metals in coastal sediments of Southern California: A critical review and synthesis. *Mar. Chem.*, 10:261–299.
- Kolpack, R. 1986. Sedimentology of the mainland nearshore region of Santa Barbara Channel, California. Pp. 57–72 In R.J. Knight and J.R. McLean (eds.). *Shelf Sands and Sandstones*. Canadian Society of Petroleum Geologists, Memoir II.
- Lee, H.J. 1994. The Distribution and Character of Contaminated Effluent Affected Sediment, Palos Verdes Margin, Southern California. Expert Report 2, Southern California Damage Assessment Witness Report, October 4, 1994. 261 pp.
- Malins, D.C., B.B. McCain, D.W. Brown, M.S. Myers, M.M. Krahn, and S. Chan. 1987. Toxic chemicals, including aromatic and chlorinated hydrocarbons and their derivatives, and liver lesions in white croaker (*Genyonemus lineatus*) from the vicinity of Los Angeles. *Environ. Sci. Technol.*, 21: 765–770.
- McCain, B.B., S.-L. Chan, M.M. Krahn, D.W. Brown, M.S. Myers, J.T. Landahl, S. Pierce, R.C. Clark, Jr., and U. Varanasi. 1992. Chemical contamination and associated fish diseases in San Diego Bay. *Environ. Sci. Technol.*, 26:725–733.
- Mearns, A.J., M. Matta, G. Shigenaka, D. MacDonald, M. Buchman, H. Harris, J. Golas, and G. Lauenstein. 1991. Contaminant Trends in the Southern California Bight: Inventory and Assessment. NOAA Tech. Memo. NOS ORCA 62. NOAA, Seattle, WA.
- O'Connor, T.P. 1996. Trends in chemical concentrations in mussels and oysters collected along the US coast from 1986 to 1993. *Mar. Environ. Res.*, 41:183–200.
- Palermo, M., P.R. Schroeder, Y. Rivera, C. Ruiz, D. Clarke, J. Gailani, J. Clausner, M. Hynes, T. Fredette, B. Tardy, L. Peyman-Dove, and A. Risko. 1999. Options for *In Situ* Capping of Palos Verdes Shelf Contaminated Sediments. Technical Report EL-99-2, U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS. (available at <http://www.wes.army.mil/el/elpubs/pdf/trel99-2.pdf>).
- Phillips, C.R., M.I. Venkatesan, and R. Bowen. 1997. Interpretations of contaminant sources to San Pedro Shelf sediments using molecular markers and principal components analysis. Chapter 16 In R.P. Eganhouse (ed.). *Molecular Markers in Environmental Geochemistry*. American Chemical Society, Washington, D.C., USA.

- Phillips, B., B. Anderson, J. Hunt, J. Newman, R. Tjeerdema, C.J. Wilson, E.R. Long, M. Stephenson, M. Puckett, R. Fairey, J. Oakden, S. Dawson, and H. Smythe. 1998. Sediment Chemistry, Toxicity and Benthic Community Conditions in Selected Water Bodies of the Santa Ana Region. Report to the State Water Resources Control Board, Sacramento, CA.
- SAS Inst. 2001. JMP Statistics and Graphics Guide, Version 4. SAS Institute, Cary, NC.
- SCCWRP. 1987. Reference Site Survey, 1985. SCCWRP Technical Report 221. Southern California Coastal Water Research Project, Long Beach, CA.
- SCCWRP. 1992. 1990 Reference Site Survey. SCCWRP Technical Report 355. Southern California Coastal Water Research Project, Long Beach, CA.
- Schiff, K.C. 1999. Sediment chemistry on the mainland shelf of the Southern California Bight. Pp. 76–88. In S.B. Weisberg and D. Hallock (eds.), SCCWRP Annual Report, 1997–1998. Southern California Coastal Water Research Project, Westminster, CA.
- and R.W. Gossett. 1998. Southern California Bight 1994 Pilot Project. III. Sediment Chemistry. Southern California Coastal Water Research Project, Westminster, CA.
- and S.B. Weisberg. 1999. Iron as a reference element for determining trace metal enrichment in Southern California coastal shelf sediments. *Mar. Environ. Res.*, 48:161–176.
- , M.J. Allen, E.Y. Zeng, and S.M. Bay. 2000. Southern California. *Mar. Poll. Bull.*, 41:76–93.
- Stephenson, M.D., M. Martin, and R.S. Tjeerdema. 1995. Long-term trends in DDT, polychlorinated biphenyls, and chlordanes in California mussels. *Arch. Environ. Contam. Toxicol.*, 28:443–450.
- Stevens. 1997. Variable density grid-based sampling designs for continuous spatial populations. *Environmetrics*, 8:167–195.
- Zeng, E.Y. and M.I. Venkatesan. 1999. Dispersion of sediment DDTs in the coastal ocean off southern California. *Sci. Total Environ.*, 229:195–176.
- and C.L. Vista. 1997. Organic pollutants in the coastal marine environment off San Diego, California. I. Source identification and assessment by compositional indices of polycyclic aromatic hydrocarbons. *Environ. Toxicol. Chem.*, 16:179–188.
- Zitko, V. 1994. Principal component analyses in the evaluation of environmental data. *Mar. Poll. Bull.*, 28: 718–722.

Accepted for publication 5 February 2007.